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THE USAF AND ALTERNATIVE JET FUEL:

HOW TO FUEL THE FUTURE OF AIRPOWER

by

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14. ABSTRACT

The purpose of this paper is to analyze three of the alternative fuels that are currently (or soon to be) available that can meet U.S. Air Force aviation fuel requirements. While commercial airlines are also beginning to show interest in alternative fuels, the significance for the military extends beyond price and includes national security concerns. The three fuels showing the most promise for aviation are natural gas to liquid (GTL), coal to liquid (CTL), and biofuel from algae. This paper compares these three fuels using six traits either required of current aviation fuel or desired for their replacement: performance, energy content, compatibility, low cost and carbon, source, and storage/transport requirements. While all three fuels meet the required performance, energy, compatibility, storage and transport requirements of aviation fuel, they fall short in some of the other desired areas. Both GTL and CTL are not low carbon, and they are also not renewable or sustainable sources. Biofuel from algae meets all of the requirements, however the current cost of production is high and it could take up to a decade for this to become a viable alternative to oil. This analysis shows that the best option for the Air Force is to invest in carbon capture technology and pursue GTL or CTL fuels for the short term. However, research and development of biofuel from algae should also continue, as this fuel shows the most promise as a permanent, renewable, and sustainable replacement for oil.

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Preface

When I first began writing this paper in 2008, the price for a barrel of oil had just peaked at nearly $150 and there was speculation that the price at the gas pumps could reach as high as five dollars. Fortunately, these predictions were wrong and oil quickly began decreasing back to sub-$100 levels. While this rise in the price of oil was shocking for automobile drivers, the commercial airlines and military aviation were faced with major budget shortfalls due to their fuel cost increases. It is now a year later and some commercial airlines have yet to recover. The purpose of this paper is to draw attention to the alternative fuels currently available for aviation and to the fact that regardless of the price of oil, an alternative to petroleum is necessary not only for aviation, but across all of our nation's energy needs.

Abstract

The purpose of this paper is to analyze three of the alternative fuels that are currently (or soon to be) available that can meet U.S. Air Force aviation fuel requirements. While commercial airlines are also beginning to show interest in alternative fuels, the significance for the military extends beyond price and includes national security concerns. The three fuels showing the most promise for aviation are natural gas to liquid (GTL), coal to liquid (CTL), and biofuel from algae. This paper compares these three fuels using six traits either required of current aviation fuel or desired for their replacement: performance, energy content, compatibility, low cost and carbon, source, and storage/transport requirements.

While all three fuels meet the required performance, energy, compatibility, storage and transport requirements of aviation fuel, they fall short in some of the other desired areas. Both GTL and CTL are not low carbon, and they are also not renewable or sustainable sources. Biofuel from algae meets all of the requirements, however the current cost of production is high and it could take up to a decade for this to become a viable alternative to oil. This analysis shows that the best option for the Air Force is to invest in carbon capture technology and pursue GTL or CTL fuels for the short term. However, research and development of biofuel from algae should also continue, as this fuel shows the most promise as a permanent, renewable, and sustainable replacement for oil.

Section 1: Introduction

> *Throughout history, energy has been the limiting factor in all military operations, whether it was Roman armies foraging for supplies, or General George S. Patton running out of fuel as he dashed across France, or the long military buildup in Desert Storm. The situation today is little different.*
>
> \- Dr. Doug Kirkpatrick, DARPA Biofuel Program Manager

Oil's status as a cheap and plentiful resource and its use as a primary fuel source across the globe has remained unchallenged for over a century. It is only within the past few decades, amid increasing signs that the era of endless oil may be coming to a close, that the search for an alternative fuel has gained momentum. This search is especially significant for the United States. As the world's largest oil consumer, the United States uses over 20 million barrels of oil per day – an amount that is nearly three times that of the second largest consumer, China.[1] There are two fundamental problems with this situation. First, oil is a finite resource. As the current wells run dry, finding new reserves of oil to satisfy the world's demand will become increasingly difficult. Second, the United States cannot support its demand for oil with the present domestic supply and currently imports nearly 60 percent of the oil needed to keep the country running.[2] While this situation leads to problems on the domestic front (such as the recent climb in cost for a gallon of unleaded fuel), it also spells trouble for the U.S. military, which must grapple with how to keep all of its vehicles supplied with fuel. This situation is particularly significant for the U.S. Air Force, which consumes 73 percent of the oil used annually by the military.[3] Now, more than five years into a second war in Iraq, seven years into a war in Afghanistan, amid decreasing stability in the Middle East as well as increasing volatility in the oil market, the United States is increasingly concerned about its dependence on oil and is becoming more involved in the search for an alternative fuel.

Unfortunately, the solution for aviation will take more than simply replacing oil with one of the other fuels available. Oil has many traits that make it a good fuel: stability, high energy density, and until recently a cheap and plentiful supply. Aircraft fuel is even more particular, requiring thermal stability, a below zero freeze point, a high energy-to-mass ratio, and a high flash point to avoid the danger of fire. Many of the alternative fuels being developed for cars, trucks and other ground-based vehicles do not meet the stringent demands required of aviation fuels.

Currently, there are two areas of alternative fuel research that are showing promise for use in aviation. The first is synthetic fuels, which are created by converting a solid feedstock first into a gas and then into a liquid. The three synthetic fuels being explored are coal to liquid (CTL), natural gas to liquid (GTL), and biomass to liquid (BTL).[4] The second area of research that is starting to gain momentum in aviation is in biofuels. There are four alternative biofuels being explored: biodiesel, biobutanol, ethanol, and algae-produced oils.[5] The prospects for all of these fuels will be further discussed in Section Three.

In addition to cost and performance, environmental concerns continue to play a larger role in the alternative fuels debate. One aspect is the desire to find a renewable source of fuel. It does little good to develop another fuel on a non-renewable source such as petroleum, for even the most abundant non-renewable resource will eventually run out. A second factor is the desire to reduce the carbon dioxide emissions created in the production and use of a fuel. It is for this reason that synthetic fuels have been put on hold – their production creates more carbon dioxide than today's oil refineries.[6] This fuel will remain sidelined until the environmental impact of its production can be resolved.

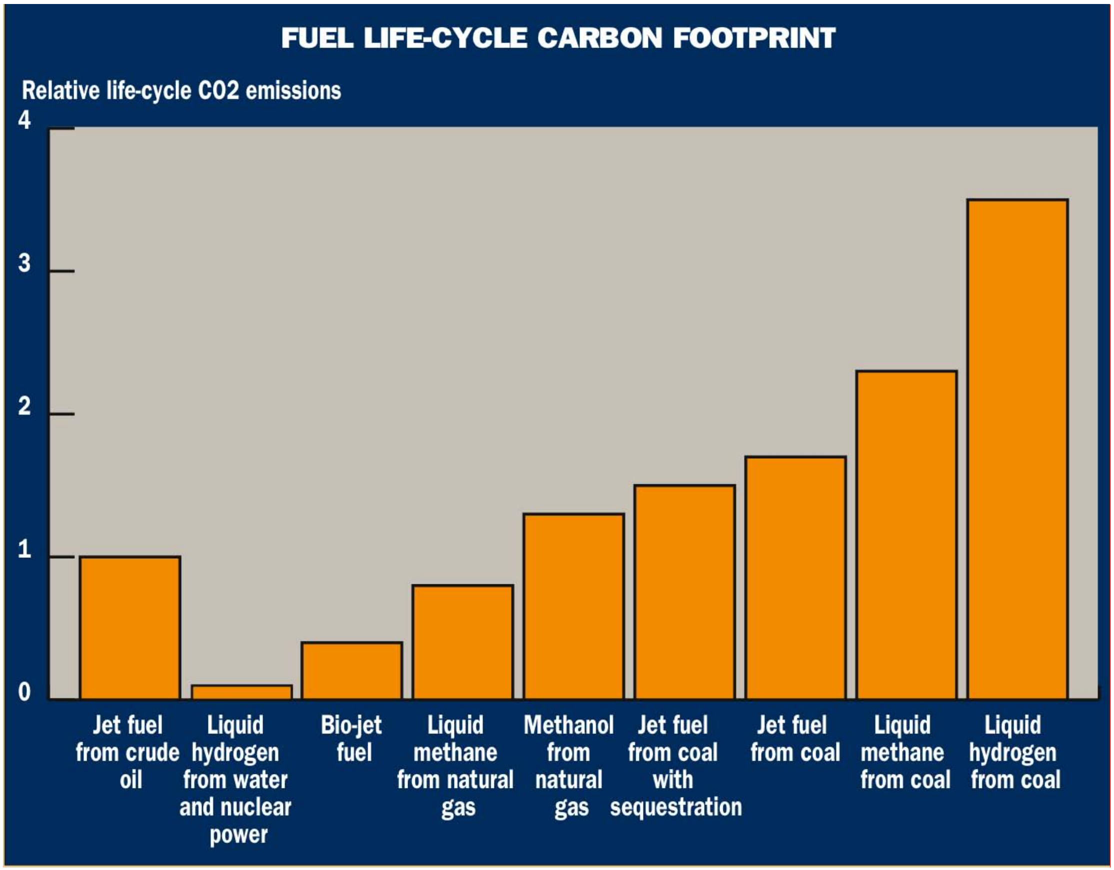

Figure 1: Comparison of Various Fuels Life-Cycle Carbon Footprint[7]

Within the military, the Air Force has taken the lead in the research and development of an alternative aviation fuel. Because the Air Force devotes more of its budget and has a greater need for jet fuel than the other services, it understandably has the most to gain or lose by finding a suitable alternative. Once validated by the Air Force, any alternative fuel can and will be used across the Department of Defense. This paper will focus solely on the Air Force's role in finding an alternative.

An important question that must be addressed, and one which is the subject of this paper is: Which alternative fuels are currently (or soon to be) available that can meet the Air Force's aviation fuel needs, and what aviation fuel options should the Air Force pursue consistent with national security objectives? This paper will show that there are currently two types of

alternative aviation fuels with high prospects for success: coal or natural gas based liquid fuel and biofuels created from algae. This paper maintains that CTL and GTL fuels should be exploited today to alleviate our immediate dependence on foreign oil; however, the Air Force should focus on biofuels derived from algae to provide a permanent replacement for oil-based fuels.

FT fuels are the best alternative for aviation today. The Air Force is currently testing a blended synthetic GTL fuel in various aircraft, and this fuel has proven to be compatible with current jet fuel specifications and performance requirements. In addition, the United States is believed to hold the greatest share of recoverable coal in the world.[8] Tapping into such a large domestic resource would improve dependability as well as alleviate many of the national security concerns regarding oil. However, these fuels are only a temporary solution, primarily because they are non-renewable and do not meet performance specifications unless they are blended with traditional aviation fuel.

Biofuels, especially biofuels from algae, are poised to become the jet fuel of tomorrow. In contrast to FT fuels, biofuels would replace oil-based jet fuels completely (not as a blend) and they offer the best prospects for meeting environmental concerns. While the research into this fuel is promising, scientists believe that large-scale production of biofuel from algae is still five to ten years away.[9] The Air Force is on the right path in pursuing an alternative aviation fuel in both FT fuels and biofuel. Pursuing both of these options will provide an alternative to oil for both today and tomorrow.

This paper will use an evaluation framework to identify and assess three of the alternative jet fuels currently under development. The next section describes how oil-based fuel became the fuel of choice and the specific traits oil exhibits that make it a good choice for aviation.

Subsequent sections discuss which alternative fuels are available and being researched today, focusing on the most promising alternative fuels being researched – coal and natural gas based liquid fuels and biofuels synthesized from algae. Based on predetermined evaluation criteria, the potential benefits and shortcomings of these fuels will be discussed, culminating in a recommendation on what course of action is best for the Air Force.

Section 2: Historical Background of Aviation Fuels

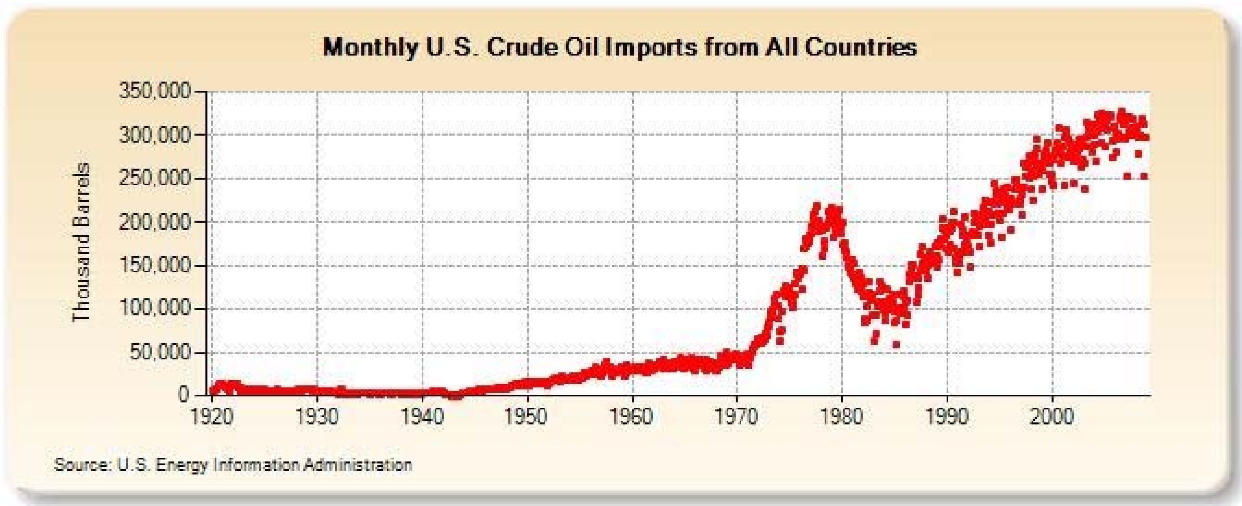

Figure 2: Crude Oil Imports to the United States, 1920 - Today[10]

The United States dependence on foreign oil is not a recent occurrence, and as the graph above depicts, America's reliance on imported oil has steadily increased since the 1950s.[11] The recent fluctuations in oil and gas prices are one aspect of this dependence, and although the media coverage focuses on the commercial side of these price changes, the U.S. military must also adjust its budget and spending to accommodate any increase in fuel costs. For the Air Force, every one percent rise in the price of jet fuel means an increase of approximately $23 million in annual fuel costs.[12] These price fluctuations have considerable impact on budget

planning considering that in 2006, the Air Force spent 82 percent (or 5.8 billion) of its energy budget on aviation fuel alone.[13]

Unlike the automobile, jet aircraft have used an oil-based fuel from their inception. Although alternative fuels have been considered over the years, previous alternatives could never match up to petroleum's combination of performance, energy content, availability and price. At times, alternative fuels were used out of necessity, such as during World War I when illuminating kerosene (typically used for wick lamps) was used due to the short supply of gasoline.[14] The military first published specifications for aviation fuel in 1944, beginning with the kerosene fuel named JP-1.[15] After World War II, the Air Force began experimenting with fuel mixtures called wide-cut fuels, which became JP-2, JP-3 and JP-4. These fuels are considered wide-cut because they contain a mixture of various types of kerosene with other flammable liquids and were developed to increase the availability of jet fuel in case of shortages (such as in times of war).[16] However, these wide-cut fuels could never match the performance of pure kerosene and the Air Force began to move away from wide-cut fuels in the 1970s with the introduction of JP-8.[17] While there are several specifications of jet fuel available today, the most prevalent are JP-8 and its commercial equivalent, Jet-A. These fuels are the benchmark for aviation, however recent increases in cost have prompted both commercial and military aviation to look for an alternative.

The commercial airline industry may be motivated by cost to find an alternative, but for the military, cost is only one aspect of the problem. Since the United States cannot feed its demand for oil domestically it must import the majority of its oil from other countries – essentially exporting control over the fuel necessary to power the military. This lack of control over a primary energy source is a national security issue, one that requires intervention on all

levels. A dependable and preferably domestic source of fuel is imperative for the Air Force to fly, fight and win both today and tomorrow's wars. The future of American air superiority depends in part on the creation and implementation of a viable alternative jet fuel.

An additional consideration is the continued availability of oil. As the demand for oil rises globally supply will begin to fall short, leading to even higher prices and increased conflict over this finite resource. In the United States, the supply of oil is one of the most controversial questions being asked in the ongoing national dialogue on energy. How much longer will oil remain a viable American energy source? The truth is that no one can accurately predict when demand will overtake supply, and this issue is subject to constant speculation since the amount of oil still underground awaiting discovery is unknown. The debate centers around a concept called peak oil – essentially the moment in time when half of the earth's supply of oil has been extracted.[18] Some geologists believe this point has already been reached while others think it could still be decades away. However, once this point in time is passed, the diminishing supply of oil will make the remaining quantity increasingly difficult to find and extract. Whether or not peak oil has been reached, the volume of oil being discovered annually has been in decline since the 1960s, and existing fields are producing up to eight percent less oil each year.[19] Waiting until the supply of oil is exhausted is not an option when a stable and secure future for the United States is at stake.

Section 3: Discussion of Alternative Fuels

Alternative fuels are the way of the future, and aviation is no exception. Interest in alternative fuels is not new, in fact both synthetic fuels and biofuels have periodically been researched and developed and both synthetic fuels and biofuels are currently being produced

commercially, at least in small amounts. This section will focus on the development of synthetic fuels and biofuels and their promise as an alternative aviation fuel today. Since the Air Force is currently investigating both of these options, the current state of military research will also be discussed.

Synthetic Fuels

Synthetic fuels offer the best alternative to oil today, and their ability to augment oil in blended fuel can immediately reduce the demand for oil in aviation by up to 50 percent. Synthetic fuels got their start in World War II, when Germany developed what is known as the Fischer-Tropsch (FT) process to create synthetic fuel from coal due to their lack of domestic or importable crude oil.[20] In simple terms, the FT process begins by combusting a carbon-based starting material to produce a gas. This gas is then fed into a reactor where it is mixed with various catalysts to produce a synthetic crude oil. This synthetic crude oil can then be refined and processed using the same systems used today for natural crude oil.[21]

Synthetic fuel production is currently limited to three primary feedstocks: coal to liquid (CTL), natural gas to liquid (GTL) and biomass to liquid (BTL).[22] These fuels can be used with minor or no modifications to current aircraft engines and they can be distributed using the existing fuel infrastructure. In addition, the FT process yields identical fuel regardless of the starting materiel, meaning that fuels created from different feedstocks can easily be blended together.[23]

Currently, there is only one commercial-scale facility producing aviation fuel using FT CTL production methods. This facility, which is operated by the South African company Sasol, currently produces around 150,000 barrels of synthetic fuel a day.[24] In the United States, the Syntroleum Company has recently begun production of GTL fuel from natural gas.[25]

The Air Force's goal is to certify all of its aircraft on a 50/50 blend of JP-8 and synthetic fuel by 2011, with the additional goal of flying half of the fleet on blend fuel by 2016.[26] The Air Force has already certified the B-52 and C-17 to use GTL synthetic fuel and has completed testing on the B-1B, F-15, F-22 and KC-135.[27] Testing has included the aerial refueling of an F-22 by a KC-135 as well as the flight of an F-15E at Mach 2.2.[28] So far, the test flights have all been made using Syntroleum's natural gas based fuel. However, the Air Force intends to test a coal-derived fuel later this year.[29]

One of the major obstacles standing in the way of full-fledged production of FT fuels is legislation passed under the Clean Air Act of 2007. Section 526 prohibits any government agency from spending taxpayer money on a fuel that emits more carbon dioxide either during production or use than current fuels.[30] Although FT fuels burn cleaner than their petroleum based alternatives, their production yields up to twice as much carbon dioxide as compared to the production of JP-8.[31] This means that until the technology to capture or sequester carbon dioxide is improved (and the price of such technology is lowered), facilities to produce FT fuels cannot be built and the government cannot purchase these fuels. This is the biggest drawback to FT fuels, but despite this problem these fuels have many traits that make them an appealing alternative for aviation fuel, and one that could be available today.

Biofuels

Biofuels are poised to become the alternative fuel of the future, and recent research indicates that algae holds the highest potential of any biofuel to date. Research into liquid biofuels in general goes back even further than synthetics, back to the 1900s when the biofuel ethanol was used in the first Model T's.[32] However, once large supplies of crude oil were discovered in Texas and Pennsylvania, biofuels fell out of favor with automakers and gasoline became the cheaper fuel of choice.[33]

There are three types of biofuels (defined as generations) currently being explored. First generation biofuels are the most common and include ethanol, biomass fuels and biodiesel. These fuels are developed from any crop with a high sugar or starch content or from plant-based oils.[34] These fuels are not ideal for mass production since they compete directly with food crops for land and water. The second generation of biofuel is called "cellulosic ethanol" and comes from fibrous plant waste such as stems, leaves, or even wood.[35] Unfortunately the process for turning this plant waste into fuel, plus the amount of waste that would be required to meet our fuel needs limits the value of this fuel. The third generation, and the one showing the most promise, is fuel derived from algae.

The idea of using algae as a fuel source is not new; in fact the U.S. Energy Department began researching how to produce transportation fuel from algae in 1978. Unfortunately, this research was abandoned in 1996 with the conclusion that the cost of biofuel from algae would never be competitive with petroleum (which at that time was only $20 per barrel).[36] However, with increases in the price of oil and better technology for oil extraction, today oil from algae holds the most potential as a replacement for petroleum.

Biofuel from algae is a completely different fuel from its generation one and two counterparts. Generation one and two biofuels are created by processing the starches or sugars of plants (or plant waste) to create an ethanol-based fuel. In contrast, biofuel from algae is processed from the oil produced by microalgae organisms. These oils are lipids and tricylglycerides similar to what is in vegetable oil and are processed into a kerosene-type (not ethanol-based) fuel.[37] This difference allows biofuel from algae to be used for more complex fuels, such as those required for aviation.

And while the pursuit of synthetic fuels seems to be on hold, the Air Force is increasing its interest in biofuels. In January, the Air Force announced its intention to acquire two types of biofuel for testing in Air Force aircraft, with the initial goal of certifying both types of fuel for use as a 50/50 blend by 2013.[38] The Air Force is not the only agency working to find an alternative aviation fuel; both Virgin Atlantic and Boeing are jointly researching the use of biofuels in commercial aviation.[39] In addition, the Commercial Aviation Alternative Fuels Initiative (CAAFI) was created in 2006 to work with organizations such as the FAA and research potential alternative fuels for commercial aviation, to include biofuels.[40]

There is no single answer to this problem, however it is clear that both the Air Force and commercial airlines need to develop an alternative to oil-based jet fuel, and sooner is better – alternative fuel development and production is a key to future national security and economic stability.

Section 4: Methodology and Explanation of Evaluation Criteria

There are many traits that have made oil the fuel of choice for aviation. Covering all of these qualities would be impractical here, therefore this paper will focus on six traits of oil-based fuels that any alternative must meet or exceed: performance, energy content, compatibility, low cost/low carbon, source and storage/transport requirements. Although JP-8 is used as the baseline for comparison, Jet-A (the commercial fuel of choice) is nearly identical and shares the same qualities as far as the examined traits are concerned.

Performance

The first trait, and arguably the most important, is that any alternative fuel must match the performance capabilities of JP-8. While there are many factors that encompass a fuel's

performance capability, this paper will analyze the following traits in order to determine any alternative fuel's suitability:

Viscosity – A liquid's amount of resistance to flow under pressure, this property will increase as temperature decreases. If viscosity is too high an engine cannot be relit in flight, therefore an upper limit is specified for jet fuel.[41] The maximum viscosity for JP-8 is 8.00 centistokes (cSt) at -20° C.[42]

Flash Point – The lowest temperature at which a fuel's vapors will ignite. Due to handling and ground safety concerns, a minimum flash point of 38° C (100° F) is specified for jet fuel.[43]

Freezing Point – For jet fuel, freezing point is measured by determining the temperature at which the last solid crystal melts, therefore this limit is much higher than the temperature at which it will completely solidify.[44] The maximum freezing point for jet fuel is -40°C.[45]

Thermal Stability – One of the most important properties, this measurement indicates a fuel's ability to absorb heat from other engine components (act as a heat sink) without breaking down into gums or particles that build up on engine components. Fuels are tested under extreme conditions to measure this property since it can take hundreds of hours of normal operation to determine inadequate thermal stability.[46] JP-8 is currently rated at 325°F for thermal stability.[47]

Energy Content

The second trait is energy content. The primary purpose of any fuel is to provide a source of energy for power. Typically, this energy is released by breaking the bonds between carbon and hydrogen molecules within the fuel.[48] Fuel is measured for both gravimetric (mass or specific energy) and volumetric energy content, and it is desirable to have a low mass/volume compared to energy content.[49] This is important because any fuel with lower energy content would require either more fuel (more weight, decreased payload) or result in less range than an aircraft fueled with JP-8.

Compatibility

The third trait is the ability to use any new fuel in current aircraft without changing engine or fuel system components or altering day to day operations. These fuels are classified as "drop-in", meaning they are interchangeable as well as mixable with today's aviation fuel.[50]

Low Cost/Low Carbon

The fourth requirement is actually two traits whose importance is intertwined. In his paper "The Fuel Gauge of National Security" Cmdr Jeffrey Eggers calls this requirement "the dual C's: low cost and low carbon."[51] It will not be enough for a replacement fuel to meet one of these requirements, in order to succeed it must be both similar in cost plus more environmentally friendly (less carbon emissions over the entire life cycle) than JP-8. Researchers estimate that in order to be competitive with current fuel costs, any replacement fuel needs to meet a two to three dollar per gallon price frame. The requirement for a fuel to have lower carbon emissions is not only desirable but also mandatory in accordance with the 2007 Energy Independence and Security Act. A provision within this law prohibits any government agency from purchasing an alternative fuel whose creation and/or use emits more greenhouse gases than conventional fuels.[52]

Source

Along the lines of low cost and low carbon, the fifth trait of an alternative fuel is its source. This encompasses areas such as production sustainability and renewable versus non-renewable resources, as well as ensuring any fuel source does not compete with land or water resources used for food production.

Storage and Transport

Finally, the last trait that is important for any alternative fuel to meet is storage and transport requirements. This encompasses everything from getting the fuel from production to distribution to aircraft to ensuring the fuel is safe for ground personnel to work with.

These six traits will be examined further in the next section.

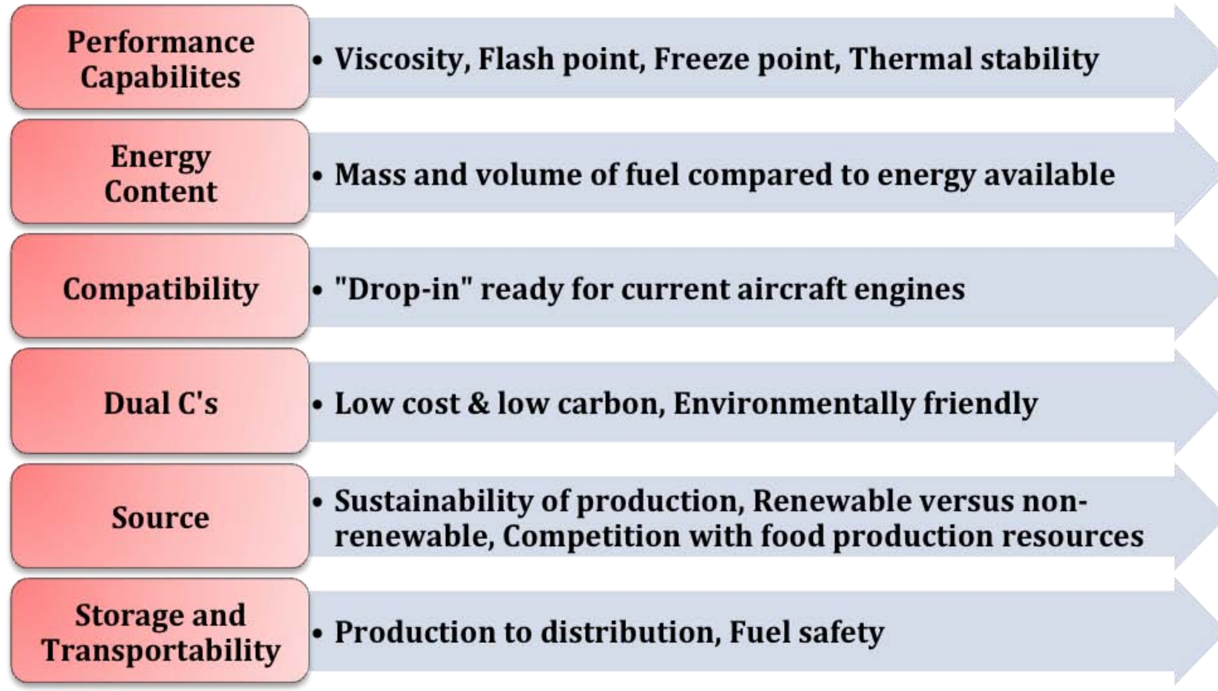

Figure 3: Aviation Fuel Traits

Section 5: Evaluation Results and Analysis

Each of the three alternative fuels will be analyzed according to the six traits described above. Because GTL and CTL are both created using the FT process, they are nearly identical fuels with the exception of their source (natural gas or coal respectively). It is important to remember that both synthetic and biofuel aviation fuels are being developed using the current characteristics of JP-8 and that the closer they match current specifications, the more likely they will be adopted for use. With that in mind, the first three areas of evaluation (performance, energy content, compatibility) do not deviate far from the standards set by JP-8. It is in the last three areas (low cost/carbon, source, storage and transport) that the strengths and weaknesses of these future fuels can be determined. One final note – the initial production cost of these fuels is

not being considered as a factor for the cost analysis portion of this paper. It would be unfair to compare these initial costs with the established mass-production costs of petroleum. The cost portion of this analysis assumes that once mass-produced, these fuels must be in the price range of two to three dollars per gallon in order to be competitive with the price of oil at approximately $90 a barrel.

Performance

	GTL	*CTL*	*Biofuel from Algae*
Viscosity	√	√	√*
Flash Point	√	√	√*
Freezing Point	√	√	√*
Thermal Stability	√	√	√*

Figure 4: Performance Analysis

√meets or exceeds requirements ≈ partially meets requirements X does not meet requirements (Note: performance standards for biofuel from algae have an asterisk to indicate this is the desired performance capability, this fuel is currently being tested to verify results.)

As discussed in the paragraph above, the performance standards for synthetic fuels as well as biofuels are very close to those for JP-8. Measurements have shown that FT fuels (CTL and GTL) tend to perform better overall than petroleum and that they have a higher flash point (less likely to catch fire on the ground), lower freezing point (can withstand colder temperatures) and better thermal stability (they can handle more heat before breaking down).[53] One problem with FT fuels is that they contain no aromatics. While aromatic-free fuel is cleaner burning, these compounds allow the seals and gaskets in an aircrafts fuel system to swell and prevent fuel leaks.[54] Since FT fuels have only been used as a blend with conventional fuel, the lack of aromatics has not been a problem. If FT fuels are used alone, additives that simulate the role of aromatics will need to be added in during the refining process. This will not affect the

performance of FT fuels and will only ensure that engine and fuel system components continue to operate as they do with JP-8.

Less data exists about the performance capabilities of biofuels, although there are reports that the Defense Advanced Research Projects Agency (DARPA) has recently been able to manufacture a fuel identical to JP-8 using algae as the feedstock.[55] In the past, biofuels have not enjoyed much support in aviation due to their tendency to freeze close to zero degrees centigrade and insufficient thermal stability. Initial research on biofuels developed from algae indicates that these problems have been solved and that a fuel matching the performance specifications of JP-8 (without blending) is possible with these biofuels.[56]

Energy Content

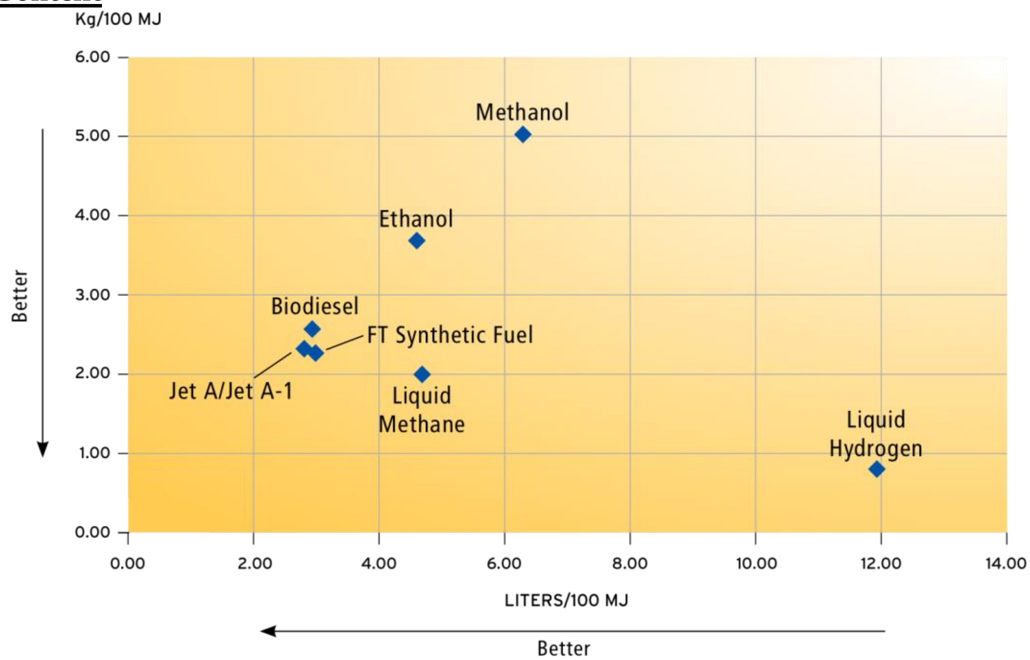

Figure 5: Mass of Fuel vs. Volume of Fuel per Unit Energy[57]

Second to performance, energy content is a critical factor for any replacement fuel. As the chart above demonstrates, FT fuels are very similar to jet fuel in energy content (the slightly higher gravimetric content and slightly lower volumetric content do not affect performance).[58]

Biofuels typically do not have the same energy content of JP-8, falling anywhere from ten percent to fifty percent short of jet fuels energy content.[59] The reason for this lies in the atomic structure of each fuel. Biofuels contain more oxygen bonds than their synthetic and petroleum counterparts and unlike carbon and hydrogen bonds, these bonds yield no energy when broken.[60] Once again, biofuel from algae shows more promise in this area since the oil from algae appears to be more similar to crude oil than what is typically extracted from a biofuel feedstock.

Compatibility

	GTL	*CTL*	*Biofuel from Algae*
"Drop-in" ready	√	√	√ *

Figure 6: Compatibility Analysis

√meets or exceeds requirements ≈ partially meets requirements X does not meet requirements

Both FT fuels and biofuel from algae are being developed so that they are drop-in ready and can immediately replace current aviation fuels. As discussed above, if FT fuels are used, aromatics must be added in order to avoid leaks from engine components. It is unclear if biofuel from algae would also require the addition of aromatics.

Low Cost/Low Carbon

	GTL	*CTL*	*Biofuel from Algae*
$3 or less per gallon	≈	≈	X
Equal or less CO^2	X	X	√

Figure 7: Carbon and Cost Analysis

√meets or exceeds requirements ≈ partially meets requirements X does not meet requirements

The dual requirements of cost and carbon are currently the Achilles heel of alternative fuels. Both FT fuels and biofuels have certain limitations in these areas that may prevent them from being accepted as alternative fuels by the commercial marketplace. To start with, the cost to build a single FT refining facility is anywhere from $2 to 4 billion dollars, and that does not

include additional costs for carbon capture and sequestration.[61] To produce enough biofuel from algae to meet current aviation fuel demands would cost anywhere from $74 billion to $2.5 trillion dollars (depending on what method is eventually selected to extract the oil from the algae).[62] While these amounts may seem astronomical, once mass-produced it is estimated that both FT fuels and biofuels can compete with oil priced above seventy-five dollars a barrel.[63] Because biofuels from algae have only been produced in small amounts and the algae growth and extraction methods are still being developed, it is not possible at this time to determine whether biofuel from algae can be competitively priced or not.

The carbon problem must also be addressed before committing to any alternative fuel choice. The European Union has proposed adding aviation emissions to existing mandatory cap-and-trade guidelines (where an airline would be responsible for purchasing carbon offsets based on the amount of carbon dioxide released), however many non-E.U. commercial carriers are fighting this plan.[64] In the United States, congress is looking to regulate the carbon dioxide standards for fuel producers instead of targeting the airlines directly.[65] In either case, carbon emissions may soon become a larger player in the cost of any aviation fuel.

FT fuels fail when it comes to these environmental concerns due to the carbon dioxide released during their manufacture. While the prospects for carbon capture and sequestration are promising, this technology will add to the final cost of these fuels. On the other hand, biofuels not only produce 60 to 80 percent less carbon dioxide over their entire life-cycle, they also feed on carbon dioxide and could be used to decrease carbon dioxide output from power plants and refineries.[66]

Source

	GTL	*CTL*	*Biofuel from Algae*
Renewable	X	X	√
Sustainable	≈	≈	√

Figure 8: Source Analysis

√meets or exceeds requirements ≈ partially meets requirements X does not meet requirements

Biofuels also outpace FT fuels when source is considered. Both natural gas and coal are non-renewable sources of fuel that will run out over time, much like oil. Although both coal and natural gas are sustainable today, once the U.S. domestic supplies are exhausted an alternative source would be required. However, biofuels are both renewable and sustainable. The supply of oil would only be limited by our capacity to grow and harvest algae. Previously it was thought that the area required to grow enough algae to satisfy demand would be impractical (in 2008, the Boeing company estimated that nearly one million square kilometers – an area the size of Belgium, would be required).[67] However, scientists are discovering that algae is a very flexible material to work with and it is able to grow and reproduce in sunlit tubes, below ground in total darkness, and even in salt water or sewage treatment facilities.[68] Another benefit is that algae do not compete directly with food or water resources like some other biofuels. It is this wide range of possibilities that scientists hope to exploit as they determine the best method of growing and harvesting oil from algae.

Storage and Transport

	GTL	*CTL*	*Biofuel from Algae*
Safe to Store	√	√	√ *
Safe to Transport	√	√	√ *
Able to use current Infrastructure	√	√	√ *

Figure 9: Storage and Transport Analysis

√meets or exceeds requirements ≈ partially meets requirements X does not meet requirements

In all of the tests completed to date, both synthetic and biofuels have met or exceeded the storage and transportation safety requirements that conventional fuels must meet. In addition, once synthetic or biofuels leave their refineries they can be transported using the same network already established for petroleum products. Due to their similarities to jet fuel, both synthetic and bio-jet fuel can also be mixed with conventional aviation fuel in blends, such as the 50/50 JP-8 and GTL fuel currently undergoing certification by the U.S. Air Force.[69]

Summary of Analysis

	GTL	***CTL***	***Biofuel from Algae***
Performance	√	√	√
Energy Content	√	√	√
Compatibility	√	√	√
Low Cost	≈	≈	X
Low Carbon	X	X	√
Renewable	X	X	√
Sustainable	≈	≈	√
Storage/Transport	√	√	√

Figure 10: Summary of Analysis

√meets or exceeds requirements ≈ partially meets requirements X does not meet requirements

Examining the summary chart above, it is clear that biofuel from algae holds advantages over FT fuels in terms of low carbon emissions, renewability, and sustainability. FT fuels only relative advantage is that they may be lower in price than biofuel from algae; however this advantage may vanish once the costs for carbon capture and sequestration are factored in. All three fuels meet performance standards, energy content requirements, and operability requirements to be used in both military and commercial aircraft. In addition, all of these fuels

can be stored and transported using the current petroleum infrastructure. Finally, the four areas that are marginal for FT fuels (cost, carbon, renewable and sustainable) are also marginal for oil. The one advantage FT fuels, especially CTL fuels, have the over oil is source: the Energy Information Administration estimates that the United States has more recoverable coal than any other nation; as a region North America is second only to Eastern Europe (to include Russia).[70]

There is one further area to discuss when evaluating these fuels – time. While biofuels appear to be the ideal petroleum replacement, their production and development is just beginning to be understood. The U.S. Energy Department believes that lowering the price of fuel from algae to a competitive level will still take five to ten more years, increasing levels of production to meet demand could take even longer.[71] FT fuels are capable of being produced today, but compliance with the emissions standards set by the 2007 Energy Independence and Security Act will take time to develop and implement. One of the biggest barriers to alternative fuels in aviation is that despite their capabilities and benefits, neither of these fuels are ready to take the place of oil today.

Section 6: Conclusion and Recommendations

Oil, once plentiful and cheap, has become an unpredictable resource that can no longer be depended on as the primary energy source for the world. In the United States, finding a domestic source of fuel is essential for both economic and national security concerns. Today, the search for an alternative energy source has expanded to include aviation. Although aircraft have used oil-based fuels from the beginning, the technology and motivation are finally available to develop an alternative aviation fuel.

The three alternatives showing the most promise for aviation are CTL, GTL and biofuels from algae. Analysis and comparison of these fuels with the common traits of JP-8 shows that both synthetics and biofuel from algae meet or exceed the performance specifications expected of jet fuel. In addition, none of the fuels examined requires changes to aircraft engine components or the storage and transport methods already in place for aviation fuel. However, CTL and GTL face the same problem as oil in that they are non-renewable and non-sustainable; additionally they have a higher carbon dioxide footprint than oil. Biofuels are low carbon, renewable and sustainable but may require at least another decade before they are ready for commercial production.

The Air Force has been working to develop an alternative fuel for military aviation and until recently was focusing solely on FT fuels developed from coal or natural gas. However, the spotlight on the high carbon levels associated with the production of these fuels has halted their development, at least temporarily. In addition, the recent advances in the development of biofuel from algae have garnered the military's attention and plans to test those fuels are in the works. The Air Force must now decide which option is better: investing in the carbon capture technology required to bring FT fuels on line or remaining dependent on oil and placing all bets on biofuel from algae.

If the Air Force continues to pursue FT fuels, it will require a higher initial investment to cover the additional costs associated with carbon capture. Now that the price of oil is decreasing, justifying this additional cost will become more difficult for both the Air Force and commercial airlines. However, the long term benefits of investing in FT fuels outweigh these initial costs, especially if the price of oil skyrockets once again. If the Air Force does not pursue FT fuels, oil will remain the only source of aircraft fuel for at least the next decade, if not longer. With the

volatility of today's oil market, it is impossible to calculate the costs of having no alternative to oil for another ten years.

By continuing to pursue biofuels, the Air Force will increase the potential for moving completely away from oil-based aviation fuel. However, making this happen will take time, money, and more time. If the Air Force does not pursue biofuels it will fall behind the alternative fuels power curve – with or without the military, the civilian sector will continue to pursue this and other alternative aviation fuels. However, military involvement in biofuels means increased investment, higher product demand, and typically more stringent testing. The commercial airlines may not have the motivation or capital to develop biofuels without the investment and support of the military.

It is this paper's recommendation that the Air Force continue to pursue both FT fuels and biofuel from algae. While the initial costs of FT fuels may be high, these fuels are ready to be produced at a commercial level and can immediately decrease the oil required for jet fuel by 50 percent. Since these fuels have been certified for use in commercial aircraft, partnerships between the military and commercial airlines could help diffuse the initial costs of getting FT production up and running, as well as the investment costs of carbon capture and storage technology.

However, FT fuels are a temporary solution and the goal of finding a permanent replacement for oil must continue. Biofuel from algae could be that solution. It is renewable, sustainable, and initial research indicates that biofuel from algae can be manufactured into a fuel identical to today's jet fuel. By remaining involved in both programs, the Air Force can utilize FT fuels to reduce aviations reliance on oil today while simultaneously developing biofuels into the future of aviation fuel and a replacement for oil tomorrow. The Air Force has a unique role

in this research, and unlike the commercial airlines, its decisions will extend beyond aviation and can impact both the future economic stability and national security of the United States.

Endnotes

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[5] Ibid.

[6] Altman, “Global Climate Change.”

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[8] EIA, “World Estimated Recoverable Coal.”

[9] Matthews, “From Algae to JP-8.”

[10] EIA, “Monthly U.S. Crude Oil Imports.”

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[45] Hemighaus, "Alternative Jet Fuels," 8.

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[60] Hemighaus, "Alternative Jet Fuels," 2.

[61] Chandler, "Fueling the Future," 41.

[62] Ott, "Algae Advances," 66.

[63] Ibid.

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[65] Ibid.

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[68] Chandler, "Exotic No More," 53.

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